MMS Observatory
Thermal Vacuum Results
Contamination Summary

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MMS Observatory

- Magnetospheric Multiscale (MMS) mission is a constellation of **four (4) identical observatories** designed to investigate the fundamental plasma physics process of magnetic reconnection in the Earth's magnetosphere.
  - The Instrument Suite (IS) on each observatory (OBS) consists of 27 instruments for plasma composition, fluxes of energetic particles, and electromagnetic fields

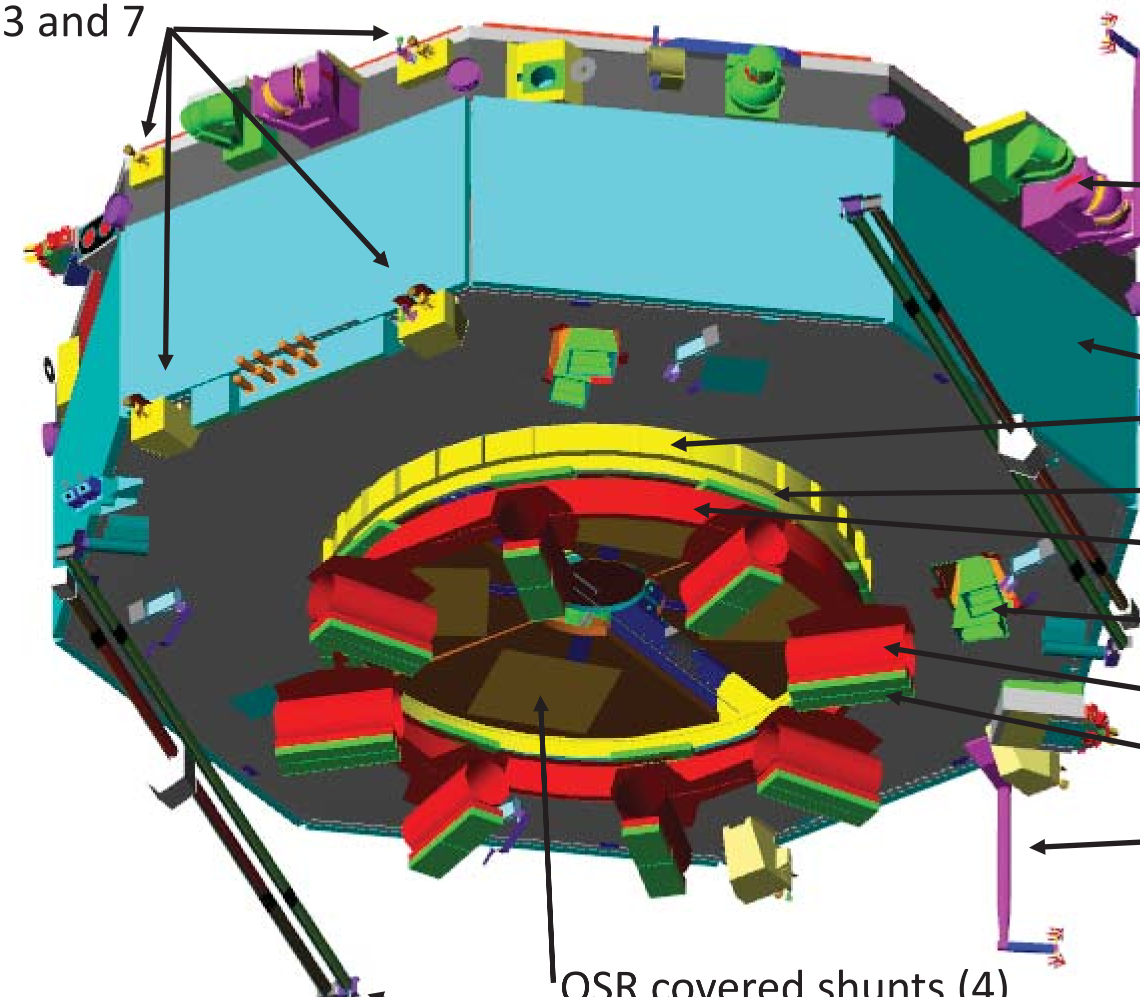
The detectors and charged particle focusing "optics" used for these measurements are sensitive to particulate and molecular contamination.

- Picture of OBS before bagging for Acoustic testing,
- Uncovered Solar Arrays and Bay 7 thrusters
- Mellinex covered IS along with some still red tag covered

- The four observatories were individually subjected to thermal vacuum exposures in the Naval Research Laboratory's (NRL) Big Blue (BB) refurbished chamber.
- A large clean room was constructed prior to TV testing, which helped stage TV preparatory activities for each OBS, outside the chamber.
- Dry runs with ground support equipment (GSE) were completed before actual OBS testing commenced. OBS testing started in November 2013 and concluded with OBS3 in early August 2014.

OBS overview

Thruster, 6 each on Bay 3 and 7



IS Deck (populated)

GPS antennas (8)

Solar Arrays (8)

Flight Passive Ring

1-inch thick G-10 (nf)

GSE Ring (nf)

Star Trackers (2)

Aeroflex Coil Springs (nf)

1 inch thick G10 (nf)

S-Band Antennas (2)

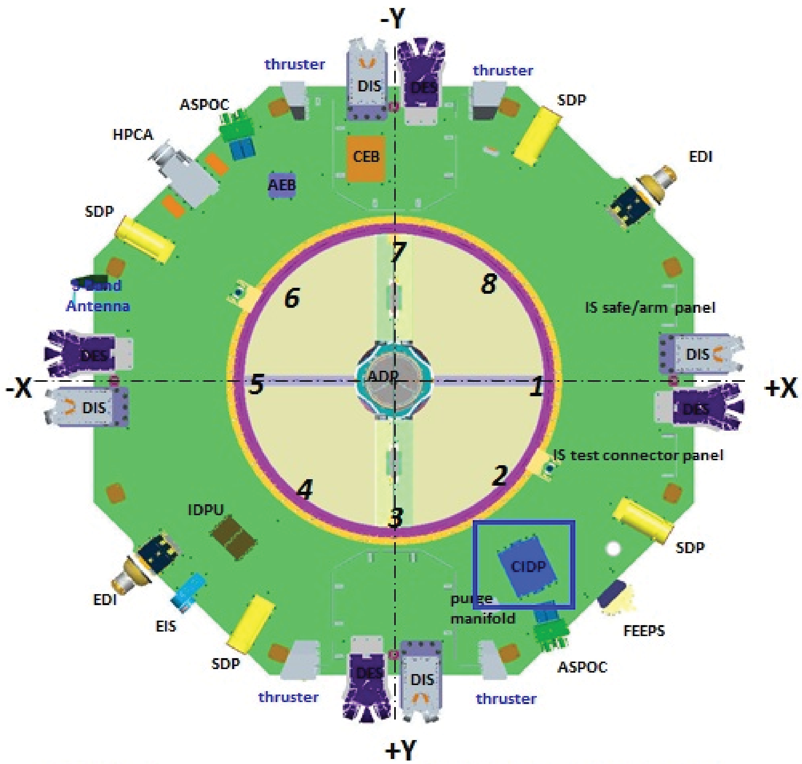
OSR covered shunts (4)

Mag Booms, partially stowed(2)

nf - non-flight

Instrument Suite Components

(View looking from the bottom of the IS deck)



- ADP - Axial Double Probe
- AFG - Analog Flux Gate Magnetometer (mounted on boom)
- ASPOC - Active Spacecraft Potential Control
- CEB - Central Electronics Box (Fields)
- CIDP - Central Instrument Data Processor
- DES - Dual Electron Spectrometer
- DFG - Digital Flux Gate Magnetometer (mounted on boom)
- DIS - Dual Ion Spectrometer
- EDI/GDU - Electron Drift Instrument/ Gun Detector Unit
- EIS - Energetic Ion Spectrometer
- FEEPS - Fly's Eye Energetic Particle Sensors
- HPCA - Hot Plasma Composition Analyzer
- IDPU - Instrument Data Processing Unit (FPI)
- SCM - Search-Coil Magnetometer (mounted on boom)
- SDP - Spin-Plane Double Probe

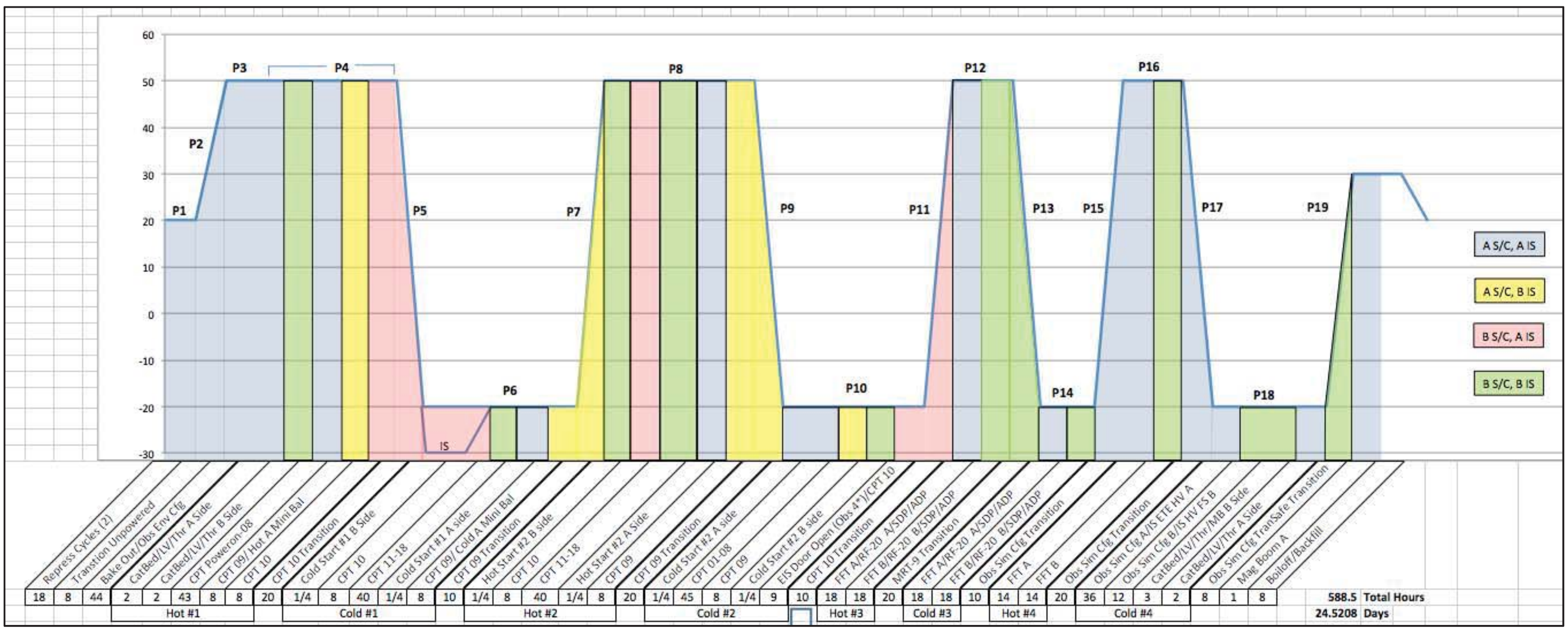
- IS detect particles and field strengths based on voltage responses.
  - Sensitive to voltage changes and electrostatic fields
  - Instruments utilize microchannel plates (MCP), sensitive to **molecular contamination**, **moisture**, and **conductive particles**) and solid state detectors (SSD), sensitive to **moisture**
- 20 instruments and sensors shown on IS deck, out of 27 total.
  - Instruments and supporting electronics came from Southwest Research Institute (SwRI), University of New Hampshire (UNH), and several other academia institutions

Thermal & Project Goals

- **General Environmental Verification Standard (GEVS) requires 4 complete cycles at OBS level.**
  - Thermally test and transition OBS Hot and Cold, after requested Bakeout.
  - Check out operational and survival OBS heaters
- **Use Hamster cage w/Cryopanels to control OBS thermally**
  - Bar heaters used to tweak temperature control for individual cryopanels.
  - Cryopanels controlled by 4 new DynaVac Thermal Conditioning Units (TCU).
- **Most electronic boxes have an A and B-side; needed to perform comprehensive tests (CPTs) under vacuum on all systems**
  - Achieve 100 hours of operation time (powered on) in vacuum on each side
- **Special tests:**
  - Achieve at least 9 hours of IS High Voltage time.
  - Preconditioning OBS hardware/heaters for 4 hour eclipse.
  - Mag Boom deployments (partial) with frangibolt activation.
  - IS door deployments (EIS)
  - Thruster valve operation and firings in hot and cold

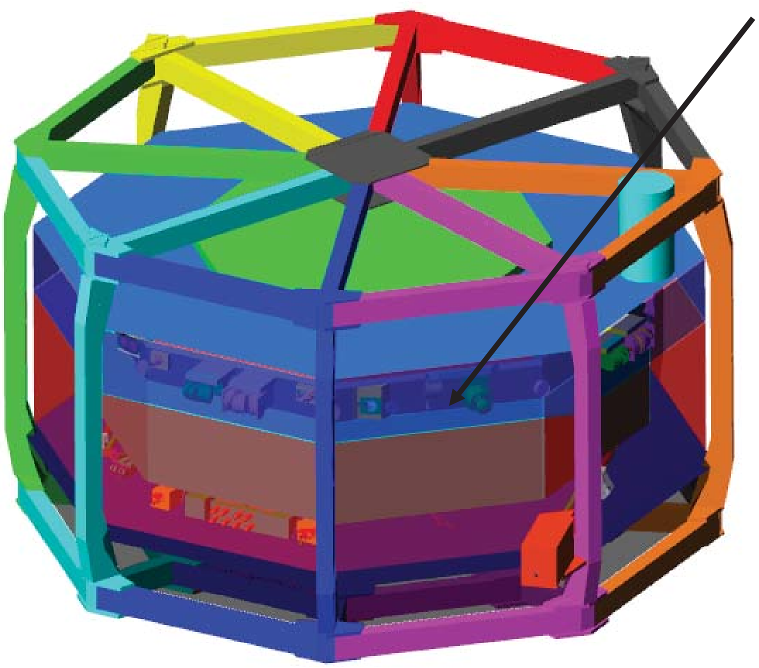
TV test profile

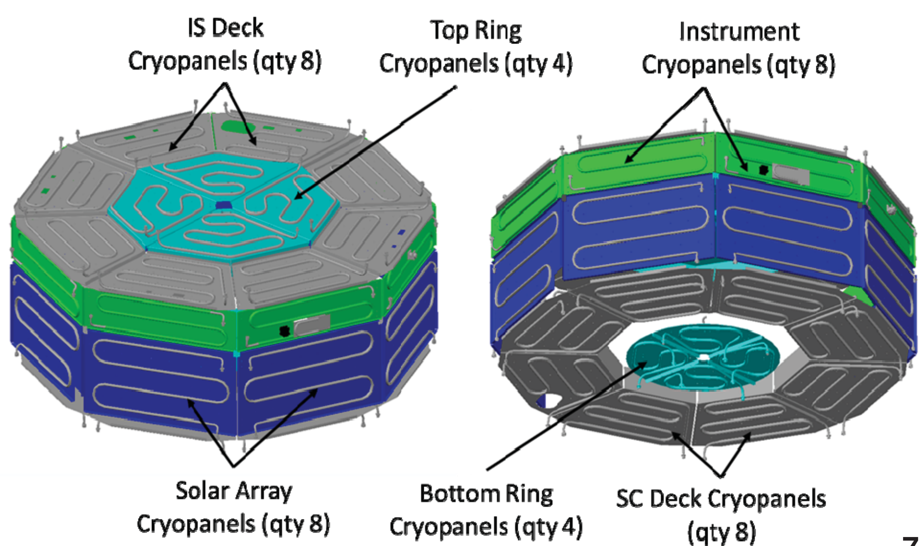
- OBS TV order was #2, #1, #4, and lastly #3.
- OBS 2 started with a Thermal Balance with balance points, then chamber break reconfigure/reset OBS subsystems and GSE, then complete 3 hot and cold thermal vacuum cycles.
  - Restarts required another (shortened) bakeout
- OBS #1, #4, and #3 had then just 4 TV cycles, as pictured below
- All observatories included hot and cold thruster fire test and high voltage testing



Test Configuration

- **Testing performed at Naval Research Laboratory using "Big Blue" chamber**
  - Dedicated cleanroom was built encompassing chamber door and surrounding processing area
- **Cold wall test, thermal cycling accomplished using thermal enclosure ("Hamster Cage")**
  - 40 cryopanels for 6 thermal zones. TCUs, omega controllers, bar heaters. A lot of plumbing, required extensive leak checking.
  - 4 QCMs: 2 viewing IS (Bays 3&6), solar array (Bay 6), S/C vent (bay 2)





Contamination Control Objectives

- **Complex set of CC objectives:**
  - Bakeout and determination of BOL outgassing rates, maintaining molecular and particulate cleanliness, maintaining low pressure for H/V testing, monitoring thruster firing
- **CC mitigations:**
  - Empty chamber precerts followed by dry runs with both “hamster cages”
  - Contam/thermal barrier in HC, to separate IS from solar arrays
  - Dedicated Scavenger Plate (SP) ducted from OBS bus vent
    - Used large chamber “Contam” Plate to retain most everything else
  - Precleaned chamber before pumpdown and installed witness foils
  - Multiple repress cycles during pump down to drive off water vapor:
    - Pumpdown and repress conducted as slow as possible to maintain stable environment (50 torr/hr to 200 torr, then 100 torr/hr to 500 torr)
  - Outgassing rate validated with 4 Quartz Crystal Microbalances (QCM).
    - Analysis generated goals to validate OBS outgassing rates.
  - 16 Ion gauges (IG) to monitor pressure and also act as instrument sources
    - Needed <1E-6 Torr for 48 to 72 hours before IS High Voltage testing
  - Monitored thruster firing with Residual Gas Analyzer (RGA)

Pressure Monitoring

- **Utilized total of 19 ion gauges**
  - Two existing chamber gauges (MKS and ion)
  - One MMS provided gauge installed in chamber wall
  - 8 gauges outside the hamster cage to stimulate FPI DES/DIS
  - 1 gauge inside the HC as source for HPCA
  - 6 gauges inside the HC solely to monitor local pressure
- **Brooks Series 355 ion gauge**
  - Compact, small size, durable metal casing
  - 2 filaments, 3 current emission modes (low-vac, med-vac, high-vac)
  - Had 2 sets of IG for each hamster cage (15 per cage).
  - Manually controlled by Granville-Phillips Model 358 Micro-Ion controllers
  - Tested temperature response in a separate test, did not find any impact
    - But to be safe, heaters used to maintain IGs above 0^{o}C

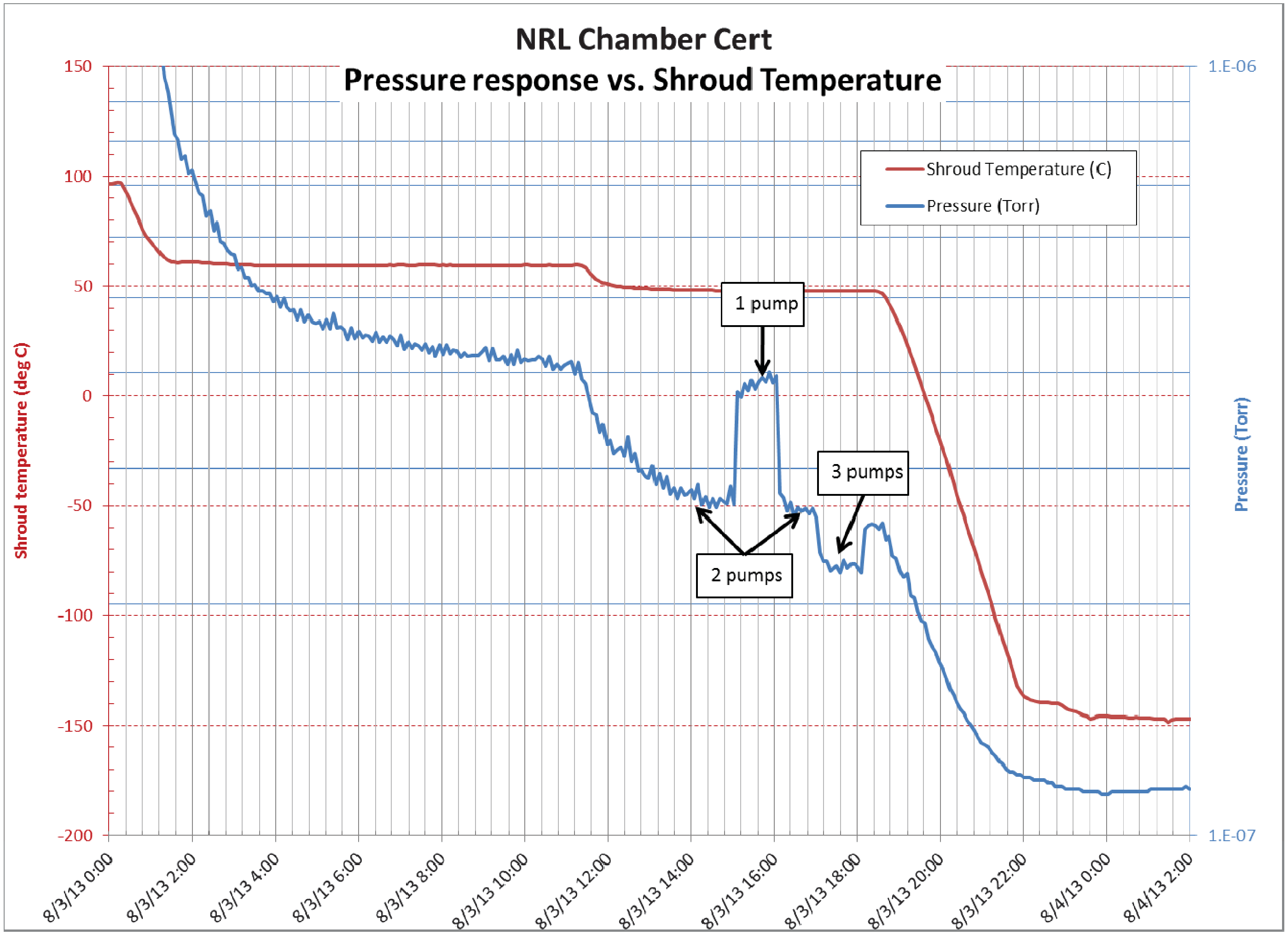
Systems designed to autonomously trigger the High Voltage (HV) safing signal for HV instruments at preset pressure levels and remain there until manually reset.

Data Acquisition

- TVAC controlled from GSFC, small core team supporting on site at NRL
- TC, TQCM, and pressure data collected by NRL-developed CDACS
  - Python based GUI control and data acquisition
  - GSFC ASIST used to control spacecraft and obtain S/C and I/S telemetry
- MMS IT team instrumental in streaming data to GSFC
  - Thin clients allowed access to the same virtual terminal from GSFC or from NRL – many CC shifts supported remotely from GSFC
  - Station screenshots posted to MMS I&T site every minute, allowed for remote monitoring during non-critical events (soak, waiting for thermal plateau…)
- CC team developed software for parsing CDACS and RGA log files

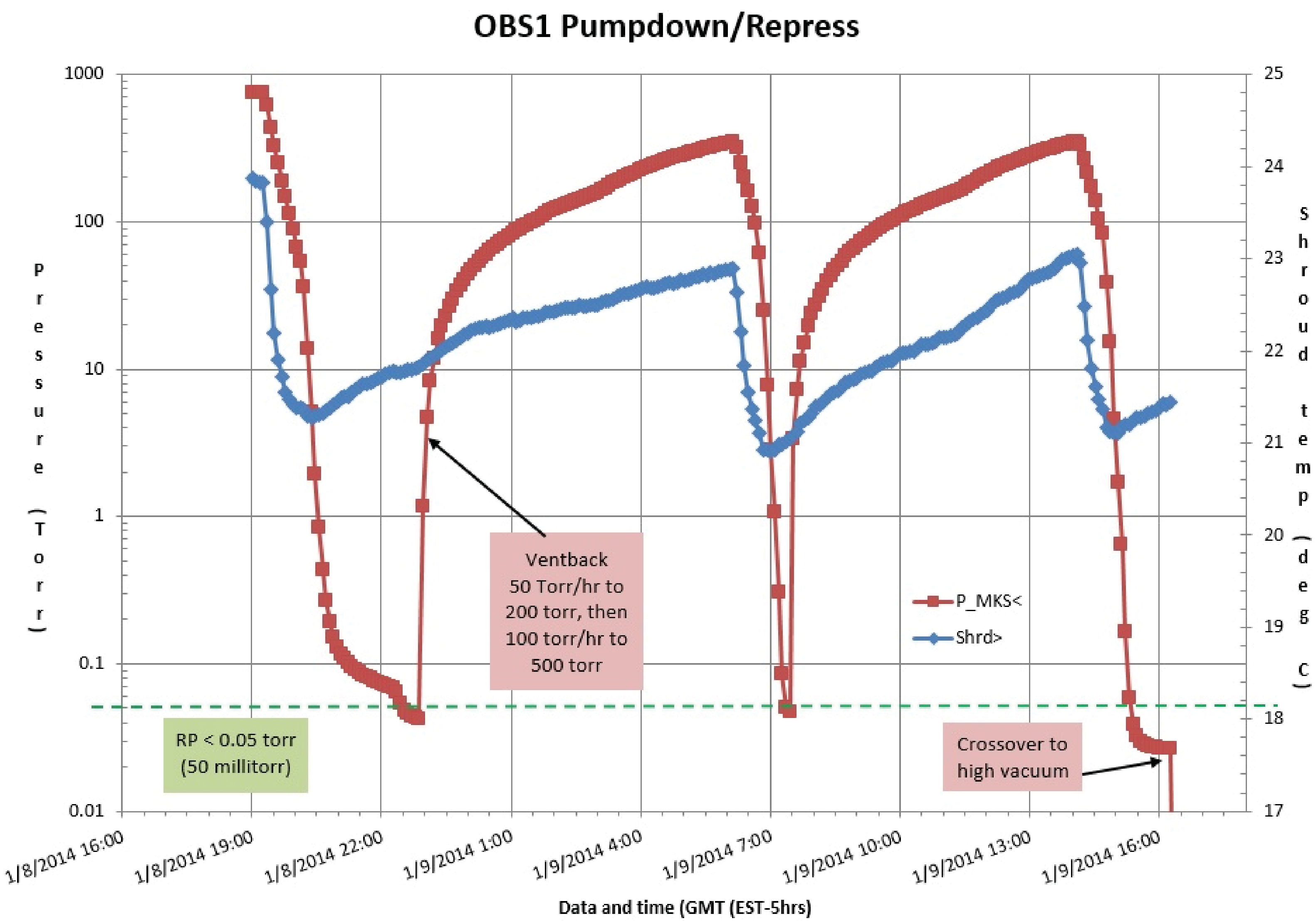
Having all TC, pressure, and TQCM data collected by the same DAQ greatly simplified anomaly investigations

Test Data



- **Chamber pressure response, operating with 1, 2, or 3 cryopumps, during precert (empty chamber).**

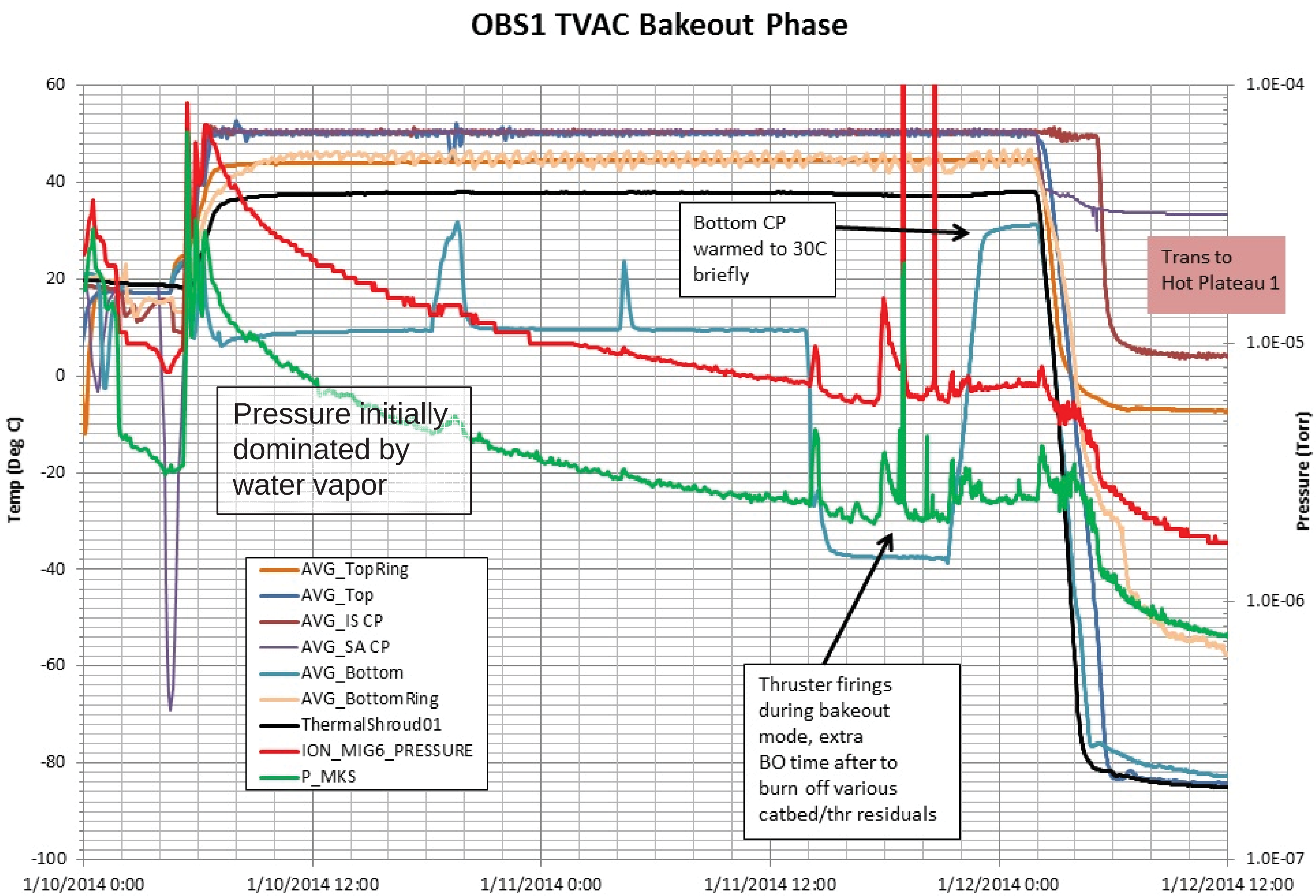
TV pumpdown curve



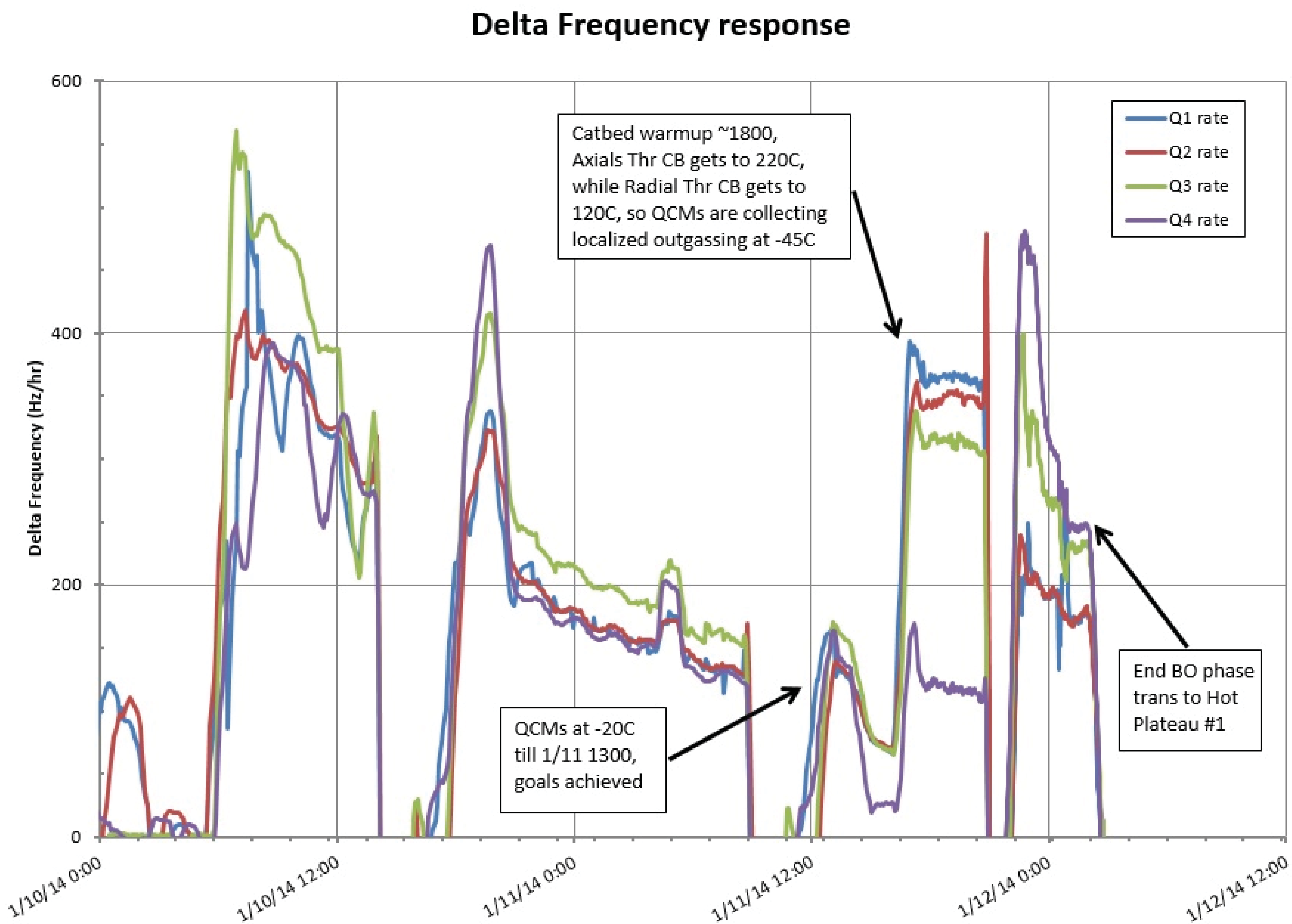
Bakeout Phase

- **Why do a Bakeout (BO)?**
  - To accelerate water vapor outgassing from OBS and GSE during prep
  - Reducing outgassing from added polymeric and epoxy materials on the OBS & GSE that still could outgas harmful chemical species to IS.
  - Allocated 48 hours in test plan, but all TV times were shorter in duration.
- **Flooded CP and SP first.**
- **QCMs set to -20C, activated the RGA, and turned on couple IG**
- **Once CP and SP < -120C, thermal then began to adjust HC cryopanel settings up in 10C increments to 50C.**
  - Idea is to have the OBS hotter than the surrounding area
  - Chamber Shrouds were also warmed up, but lagged cryopanels by 10C. Shrouds only got to 30-40C.
- **Monitored BO with QCM and RGA.**
- **QCM goals set based on meeting OGR of ~1E-12 g/cm^2/sec.**
  - Looked for meeting QCM delta frequency goals and achieving DDF <5 before calling it done.
- **Perform 1st of thruster firings at end of BO**

Bakeout Phase
Pressure response



Bakeout Phase
QCM data response



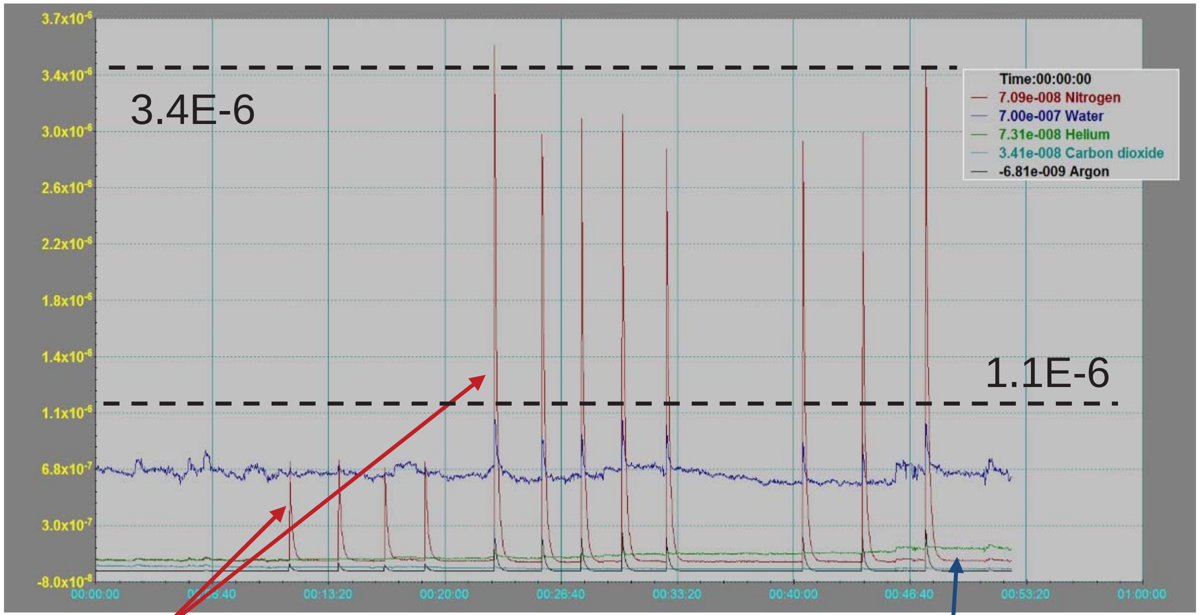
Bakeout Phase
OBS Outgassing Rates

QCMs	Cryopanel Location	OBS2 Tbal 11/5/13 2200	OBS2 TC 12/4/13 0600	OBS1 1/11/14 0800	OBS4 2/15/14 0930	OBS3 6/29/14 2340 part1	OBS3 7/16/14 1700 part2
1	Bay 2 IS (near vent)	2.4E-13	1.1E-13	6.1E-13	4.8E-13	5.5E-13	2.3E-13
2	Bay 3 IS (DIS/DES)	7.0E-13	2.4E-13	1.8E-12	1.3E-12	7.5E13	2.7E-13
3	Bay 6 IS (near HPCA)	2.6E-12	6.6E-13	2.8E-12	2.1E-12	1.3E-12	4.2E-13
4	Bay 6 SA (center panel)	2.6E-13	1.1E-13	2.6E-12	5.8E-12	1.3E-12	5.5E-13

- Outgassing rates (OGR) verified that req'ts were met <1E-11 g/cm^2/sec.
- Established QCM delta frequency goals to achieve ~1E-12 g/cm^2/sec during Bakeout phase. Expected low OGR due to subsystem bakeouts.
- QCM4 data typically higher due to molecular condensation on colder Bottom Cryopanels and then they were warmed up. OGR before warm up, always lower.

Thruster firing

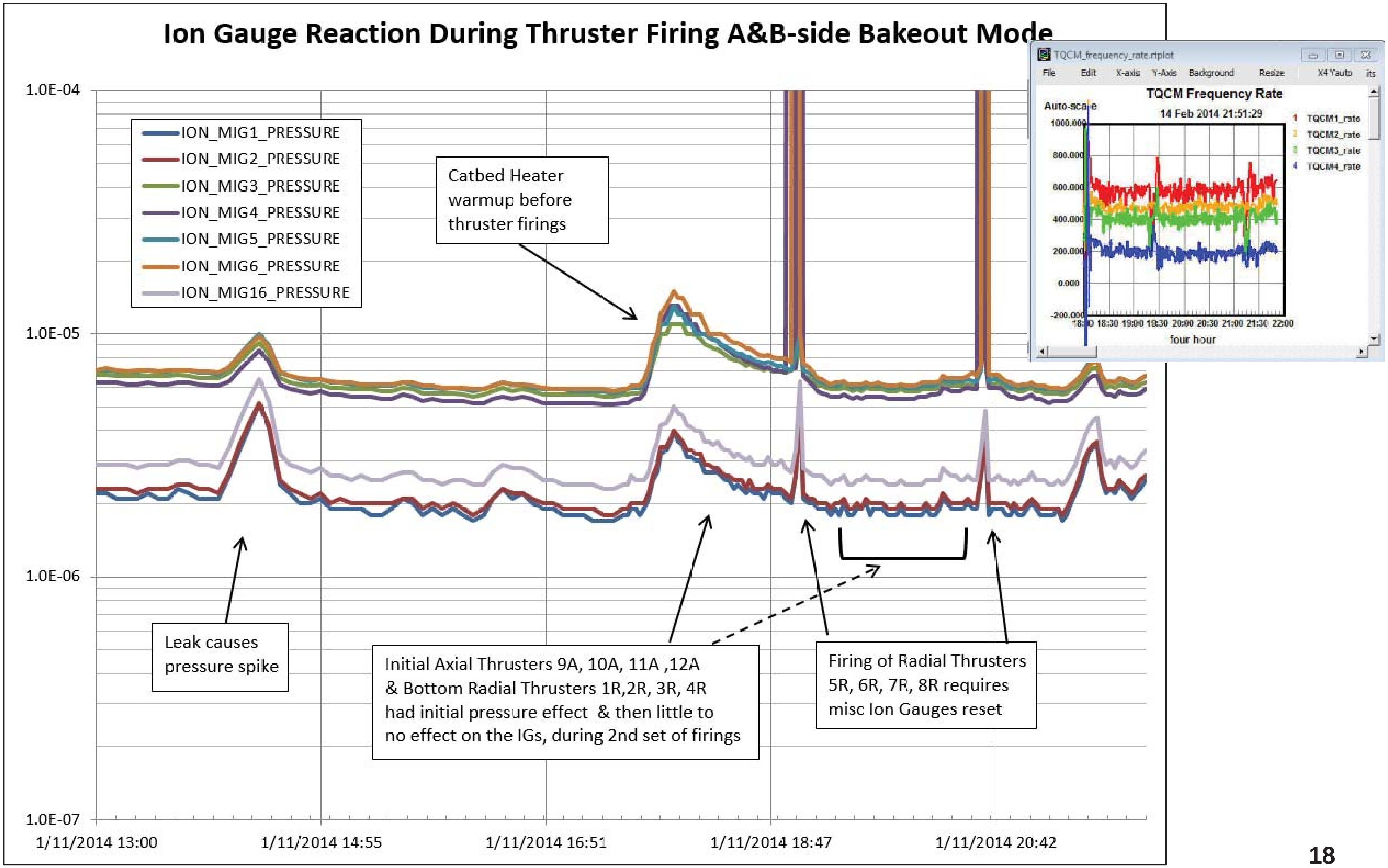
- **Propulsion group tested response of 4 axial and 8 radial thrusters by firing each for ~ 50 milliseconds at hot and at cold plateau**
  - Tanks filled with GN2 (28 amu) with argon (40 amu) tracer, **no hydrazine**
  - CC not necessarily concerned from actual gas depositing onto IS surfaces from thruster firings but it was “deemed good” being hot biased initially.
  - Main concern with catbed activations – reaches 220C for axial and 120C for radial thrusters. The localized polymeric and epoxy material could outgas significantly during this preparation for thruster firings.
  - Performed with A-side and B-side CDH and PSE ebox activation, separated by 2-3 hours in TV.
- **Critical to avoid helium and purge all prop lines due to lack of turbo pump.** Cryopumps have very limited Helium pumping capacity!
- **Prop testing monitored by CC with RGA switched to pressure vs. time mode**



Pulses corresponding to thruster firing

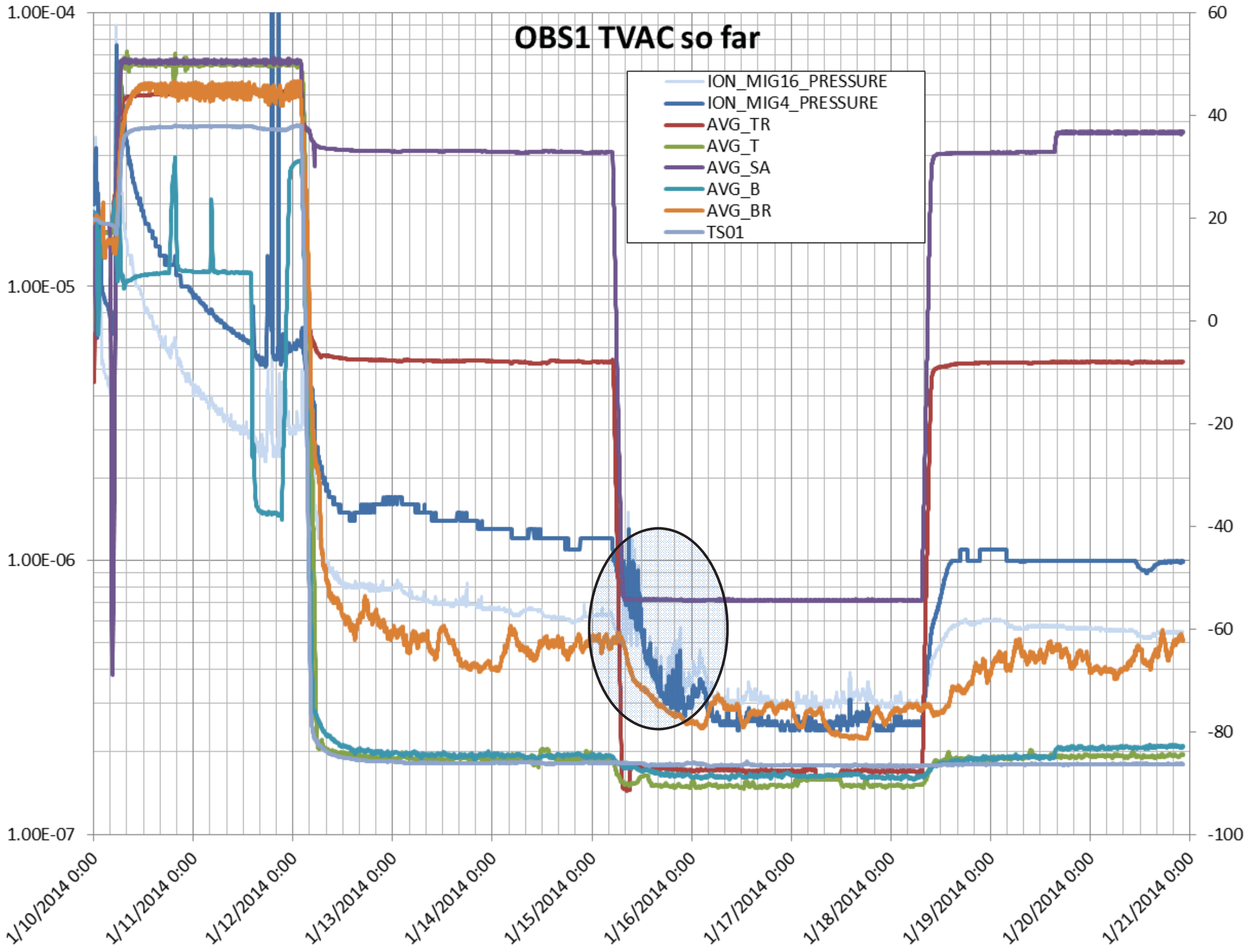
Also monitored Helium

Thruster firing
Pressure and TQCM response

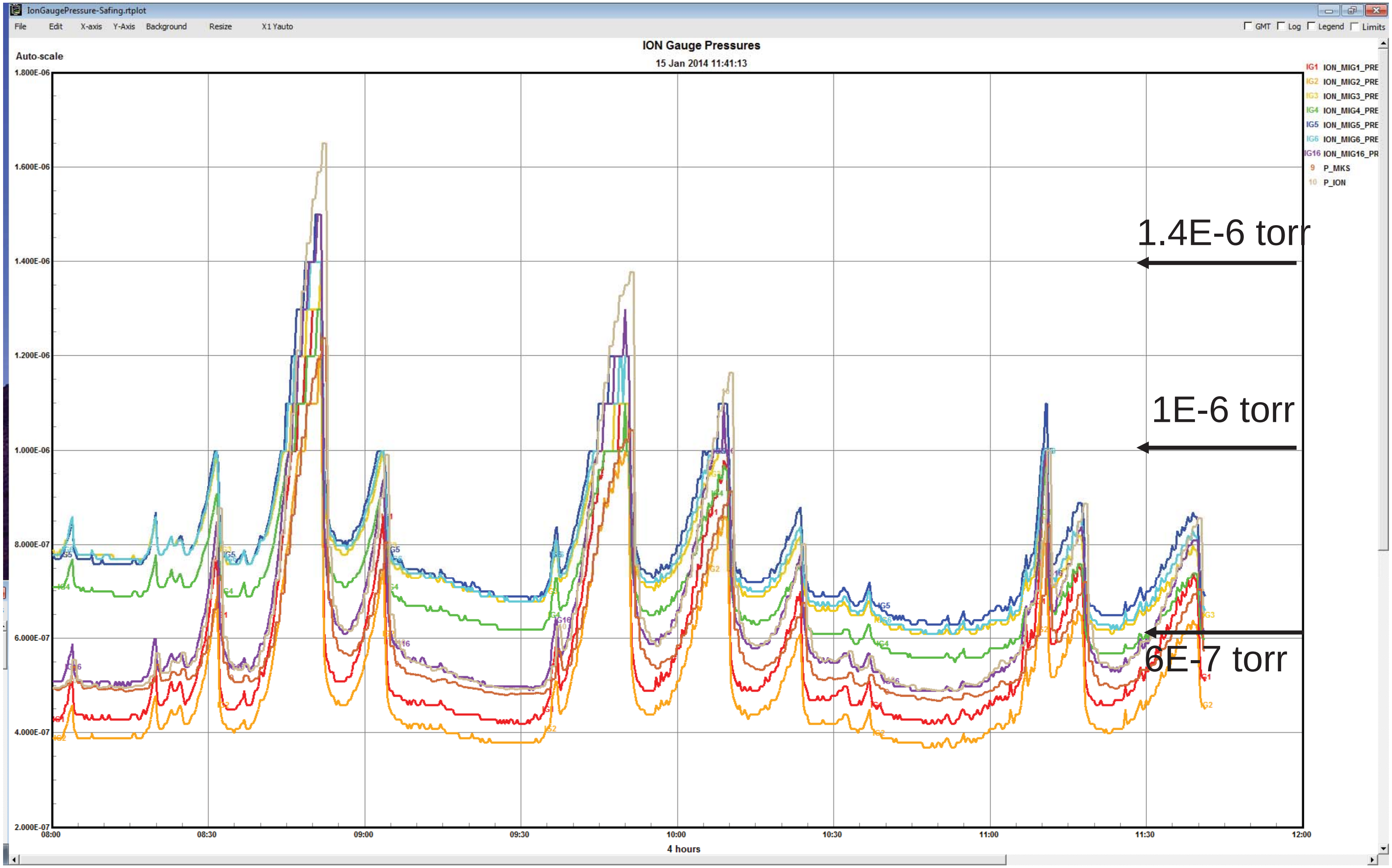


OBS Thermal Transitions

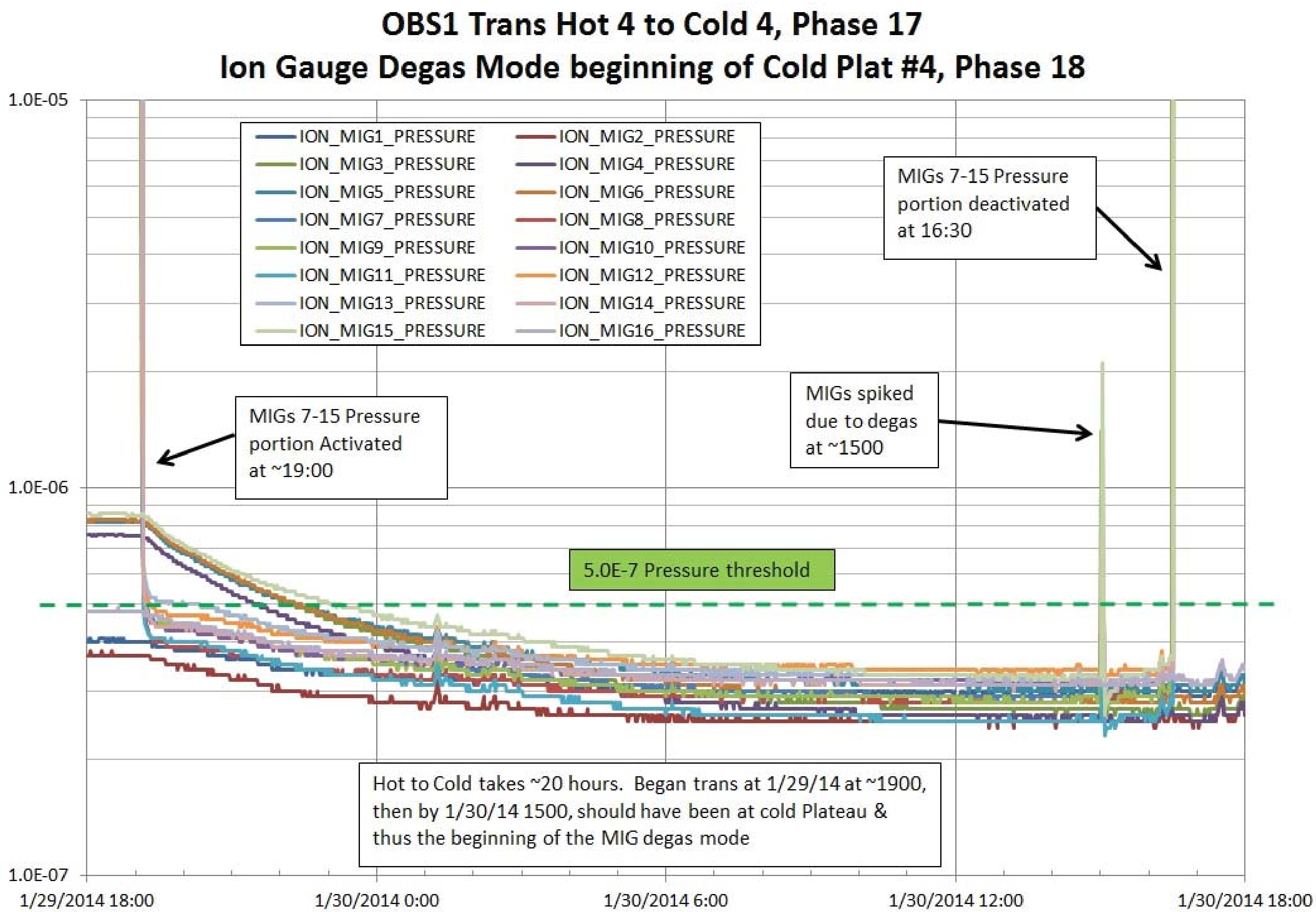
- **CC Monitoring during thermal transitions critical**
  - Desired to maintain <1E-6 Torr at all time to avoid resetting timer for H/V testing
- **Necessitated slow transition rates and maintaining > -90C**



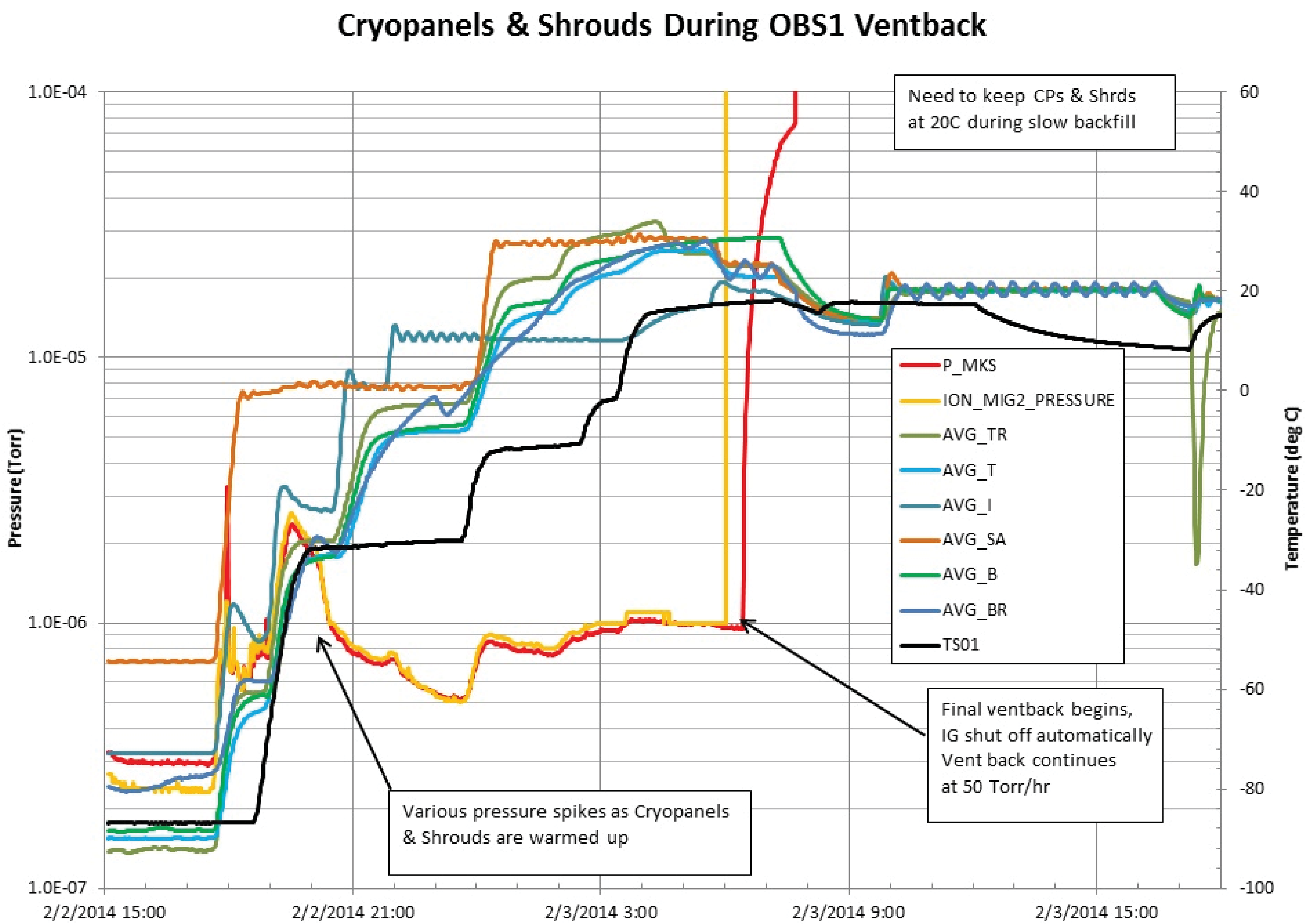
Ion Gauge response



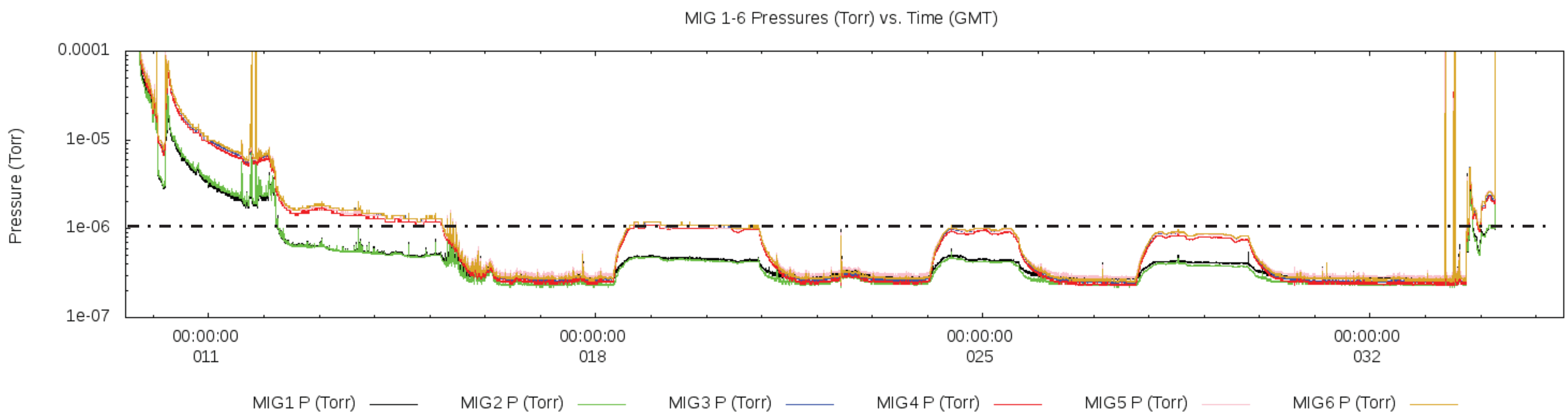
Ion Gauge response
Hot Plateau to Cold Plateau



OBS WarmUp in Stages



OBS1 Thermal cycle pressure levels



Started January 9, 2014
Ended February 2, 2014

MIGs 1 & 2 external to HC
MIGs 3-6 are internal to HC

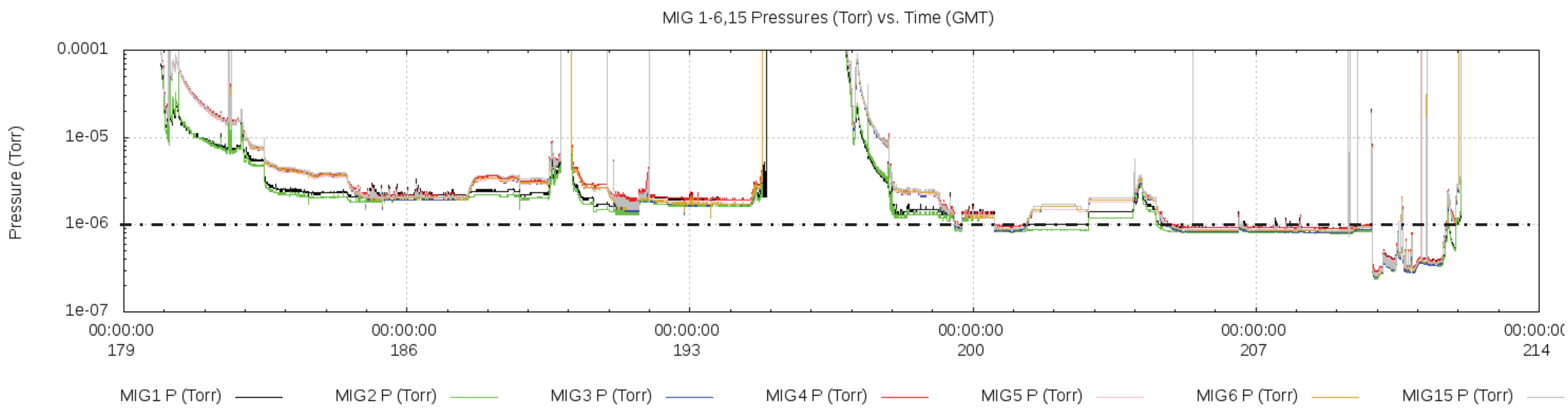
OBS3 TV issues

- **Elevated High pressure levels from start of TVac to almost finish!**
- **How to remove Helium and Nitrogen from chamber?**
  - Performed numerous Cryopump regenerations and even tried cycle purging
  - Eliminated Prop tanks from being the source of either gas
    - No partial pressure gains from Thruster firings and analytically ruled out
  - Backfilled to 100 torr, did NOT reduce Helium
  - Leak checked with Argon, nothing really noticed consistently
  - Backfilled to ambient pressure; installed “cobbled” Turbo Pump setup (Webb)
    - Helium now successfully removed (not by TP though), but now high levels N2
  - Decided to run with all 3 Cryopumps open; held just 1E-6 torr in Cold Plateau
  - Thermal minimizes temperature changes, minimum Cryopanels to -85C
    - IS team nervously goes forth with HV testing and completes
  - Realized that manual vent valves for CP, QCMs, SP discharge were all closed (from leak testing)
    - Opened and relieved back pressure through cryo flex lines, pressure stabilizes..
    - Until they freeze over. Needed to melt iceball (Tooley with blow torch)

Other OBS3 TV issues

- **Were we in the clear? Barely, proceeded to settings for Eclipse**
  - Preheated OBS, then all Chamber shrouds & cryopanels were flooded w/LN2
  - Momentary large pressure spike to 1.2E-5 and then all quiet!
  - The Big Freeze appears to seal all the leaks & reseats chamber burst disk
  - Pressure holds <4 E-7 torr for remainder of testing.
- **Other test support apparatus failed during testing as well**
  - Solenoids became stuck at various times
    - Initially in checkout with Omega 10, controlling Bottom ring cryopanel, became SP!
    - The later again later when in Cold Plateau #4, PL melts iceball w/torch
  - TCU #3 failed early, middle, and wasn't used much after that, until Eclipse
    - Trip a circuit breaker, set off alarms, purge line left open during pre-TV checkout
    - Boom (heard at NRL) relief disk burst, in-line supply too fast (5C/min vs. 1C/min)
    - Found to be a source of N2 leaks, taken off line. Rough pump attached to it for days. Thermal uses heater bar control for Solar Array temperature control.
- **Project polled IS and OBS near end of CP#4. Nobody wanted to conduct any additional testing (even though pressure issues seemed resolved) so the TV test ended without anymore issues.**

OBS3 Thermal cycle pressure levels

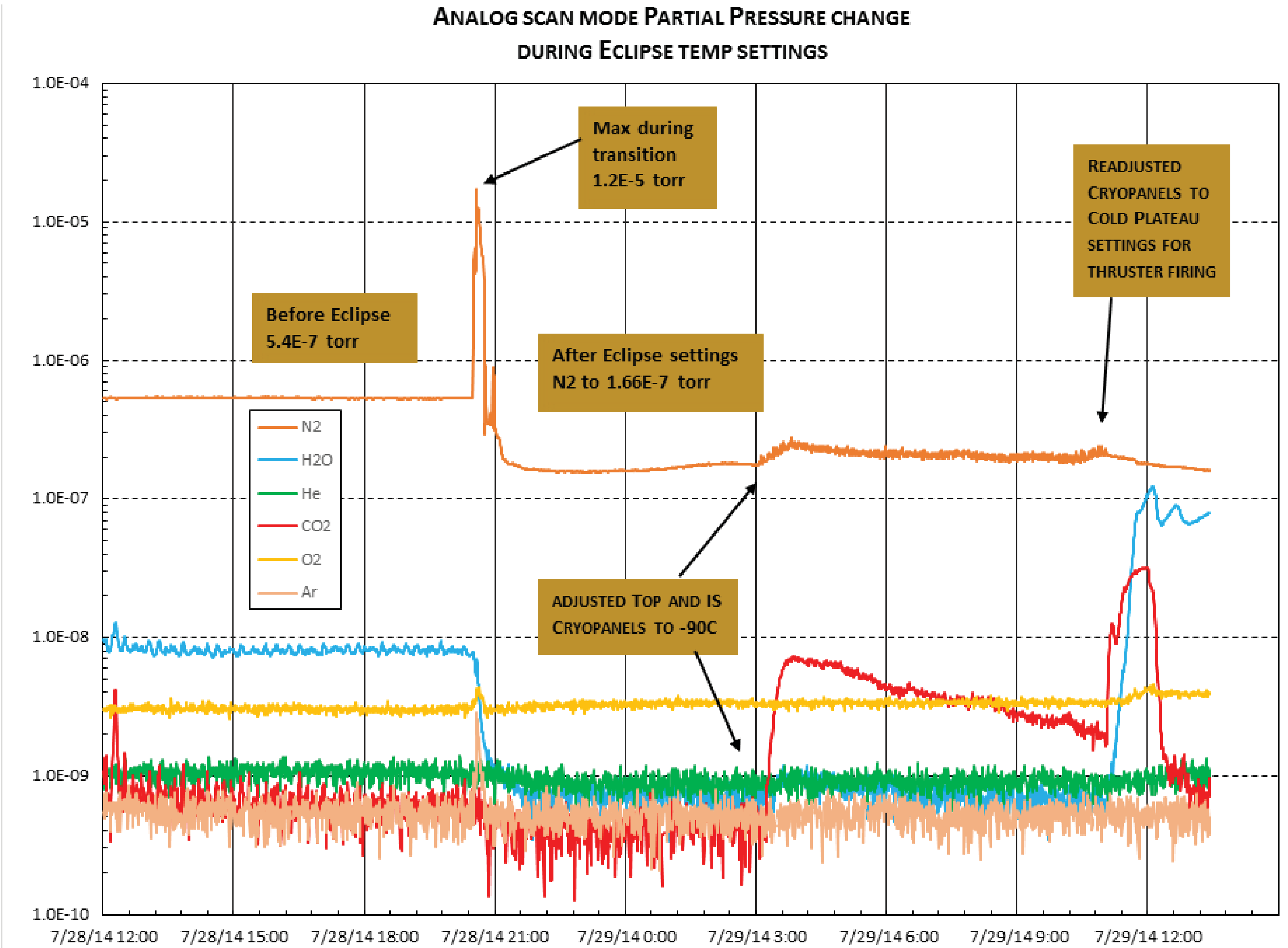


Started June 27, 2014
Ended July 14, 2014 am Part 1

ReStarted July 14, 2014 pm
Ended July 31, 2014 Part 2

MIGs 1, 2, &15 external to HC
MIGs 3-6 are internal to HC

OBS3 Pressure “Relief”



Lessons Learned

- After 4 TV tests, we still didn't capture every step, recall every chamber operating nuance to make the TV tests go 100% smoothly.
- Very complex setup, tight confines, lots of mechanical and thermal hookups required. Leak checked every time, perhaps too much Helium used in progress. Consider using Argon as well.
- Operated TCUs in ambient temperature and still couldn't detect all the connection leaks. Figure better way to detect leaks.
- Certainly Need vacuum to validate operation of chamber systems beforehand; during Dry Runs & precerts.
- Don't turn off Observatory heaters too soon. Needed to maintain OBS warmer than surrounding panels and GSE.
- Ion gauges were ideal for protecting IS from exposures to pressure spikes during HV operations.
- Real-time monitoring, shift test logging, and cross training project personnel has it's benefits.
- Expect to have problems. Have backup safety plans to secure HW.